ARRAY OF SUBARRAYS USING ADAPTIVE ELEMENT PATTERNS

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***Abstract* — This paper explores the use of subarrays as array elements. Benefits of such a concept include improved gain in any direction without significantly increasing the overall size of the array and enhanced pattern control. The architecture for an array of subarrays will be discussed via a systems approach. Individual system designs are explored in further details and proof of principle is illustrated through a manufactured examples.**

***Index Terms* — Adaptive arrays, antenna arrays, mutual coupling, beam forming.**

I. INTRODUCTION

Since its adoption, antenna arrays have improved the performance of wireless communication systems by increasing its efficiency, reliability and performance. It also allowed for dynamic beamforming techniques which enabled adaptive smart antenna technology and direction finding applications. An increase in antenna array elements provides higher gain, increased channel capacity [1] and enhanced control over radiation peaks and nulls [2]. Conventionally, array elements are spaced at distances of $\lambda/2$ to avoid excessive mutual coupling.

The radiation pattern of an array can be considered as the product of the individual element pattern and the array factor. Adaptive array patterns are achieved by varying phase excitation of the array elements. Directive element patterns provide increased gain, but omni-directional elements are commonly in applications where wide-angle steering is required. In such cases, the gain is solely determined by the array factor. Alternatively, the gain of an array can be improved by employing adjustable element patterns. This can be achieved through the use of adaptive antennas as array elements [3].

In this paper, the concept of an array of subarrays is proposed. The omnidirectional array elements are replaced by compact subarrays, without increasing the overall size of the array significantly. The subarrays are spaced 0.5λ apart, but the individual elements of the subarray are closely spaced (typically 0.1λ to 0.2λ). Consequently, mutual coupling between elements of the subarray would be high. This can be alleviated through the use of decoupling and matching networks (DMNs) [4]. The concept of array of subarrays will be illustrated by considering a uniform circular 3-element array, with each "element" being a subarray of closely spaced monopoles.

II. ARRAY ARCHITECTURE

The topology for an array of subarrays is shown in Fig. 1(b). The 3-element circular subarrays are centered at the position of the conventional array elements in Fig. 1(a). Subarray elements have an inter-element spacing of d, where $0.1\lambda \leq d \leq 0.2\lambda$. Exceeding the lower boundary of d results in excessive mutual coupling and loss of directivity. Similarly, surpassing the upper limit of d would result in high coupling between elements of neighboring subarrays, which is not accounted for in the design.

The architecture for the array of three subarrays is shown in Fig. 2. Each subarray employs three closely spaced vertical monopoles with symmetric DMNs. Banks of independently controlled phase shifters are utilized to individually control the radiation pattern of each subarray. These are connected to the output of a bank of 3-way equi-phase, equi-amplitude power dividers for even power distribution to array elements. Finally, another bank of phase shifters and a power divider is used to provide control over the array factor.

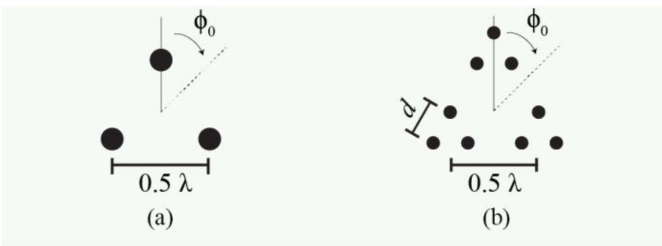


Fig. 1 Topology of (a) conventional 3-element array and (b) proposed array of subarrays.

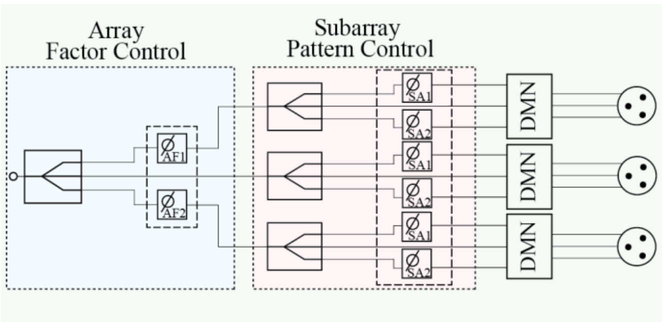


Fig. 2 Array architecture for 3-element array of subarrays.

III. DESIGN

The array was designed at a frequency of f = 2.45 GHz. All array components were fabricated on Rogers 4003C substrate (ε_r = 3.55, tan δ = 0.0027, thickness = 0.787 mm).

A. Subarray & DMN

Subarrays were manufactured and tested individually. The three monopole elements of the subarray were mounted on a hexagonal board to ensure symmetry. An element spacing of 18.28 mm (0.15λ) was used, with each monopole having a thickness of 1.5 mm and a length of 22.5 mm. In addition, a DMN was designed following the approach described in [5], and was etched on the bottom layer of the board, as seen in Fig. 3a.

The DMN provides matched input ports and high isolation between them. With the addition of the DMN, port coupling $|S_{12}|$ is reduced from -6.8 dB to -17.6 dB (see Fig. 3b).

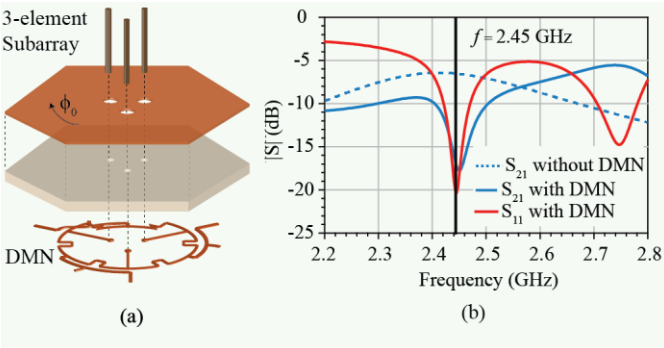


Fig. 3 (a) Layered model of 3-element subarray of vertical monopoles with a DMN on the bottom layer of the substrate. (b) Scattering parameters of the subarray with and without the DMN.

B. Phase Shifters

Switched-line phase shifters are used for beam switching of both the array factor and subarray pattern. The phase shift required for maximum gain was determined for prescribed directions in 30° increments ranging from 30° to 360°. This was done using CST MWS [] to account for mutual coupling and the influence of the DMN on the element excitations. As an example, the required phase shifts for array factor control (ϕ_{AF}) and subarray control (ϕ_{SA}) for maximum gain in the four principle directions (ϕ_0) are shown in Table I.

Hittite HMC545E SPDT switches are used to adjust the phase shift using digital control signals. The number of bits required was reduced by introducing an offset to the reference line. This in turn reduces the complexity and the insertion loss of the phase shifter, while achieving all the required relative phase shifts. The layout of the phase shifter circuit is shown in Fig. 4.

TABLE I
PHASE SHIFTS FOR MAXIMUM ARRAY GAIN

ϕ_0	ϕ_{AF1}	ϕ_{AF2}	ϕ_{SA1}	ϕ_{SA2}
90°	-210°	-210°	-330°	-360°
180°	-90°	-270°	-30°	-60°
270°	-150°	-150°	-60°	-360°
360°	-270°	-90°	-330°	-300°

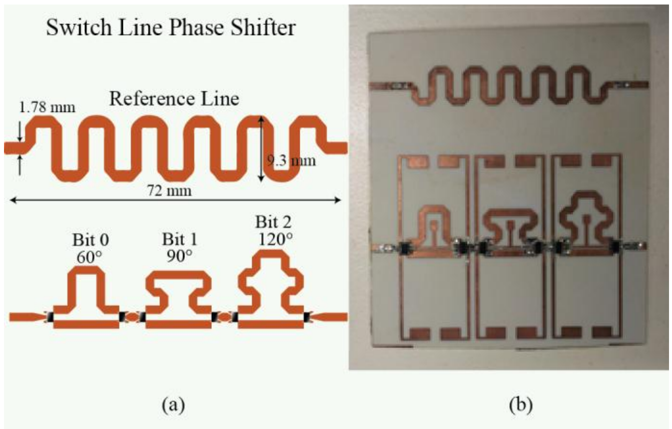


Fig. 4 (a) Layout of for switched-line phase shifter with meandering reference line. (b) Photograph of fabricated phase shifter.

C. Power Divider

The 3-way power divider design was adopted and modified from [6] to deliver equi-phase and equi-amplitude response. The circuit was fabricated with the layout shown in Fig. 4(a)-(b). Measured results agree well with simulated results, as shown in Fig. 4(c)-(d).

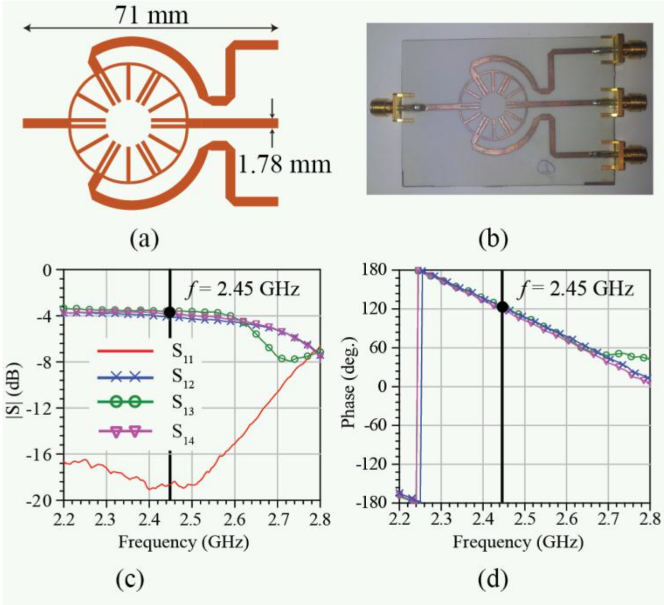
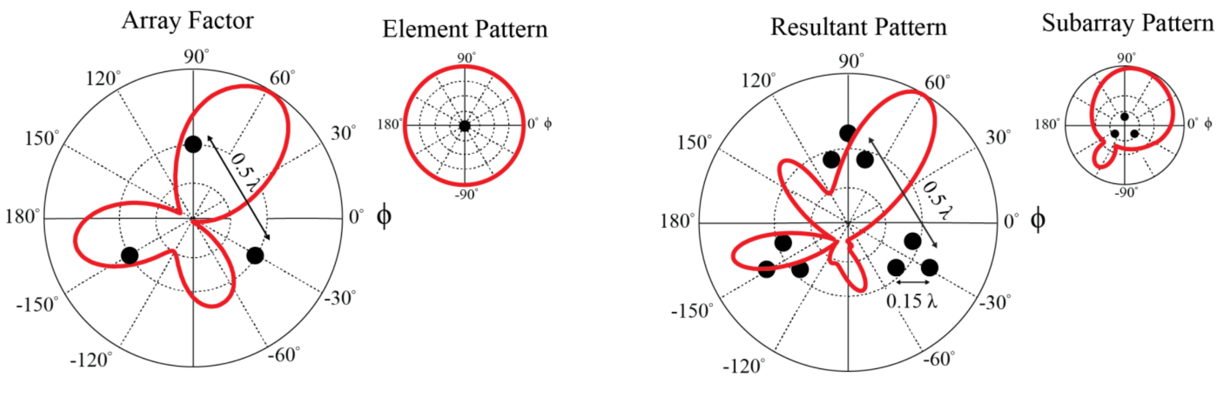


Fig. 5 (a) Layout of 3-way Bagley polygon power divider. (b) Photograph of fabricated power divider. (c) Measured scattering parameters of power divider. (d) Measured phase response of power divider. Symbol ● indicates ideal value at design frequency.



(a) (b)

Fig. 6. Normalised radiation pattern for (a) conventional 3-element monopole array with 0.5λ element spacing and (b) array of 3 subarrays, with a spacing of 0.5λ between the subarray centers. Subarray elements are spaced 0.15λ apart. Both array factor and sub-array pattern have a maximum gain at 60°.

IV. RESULTS

The gain of the array of subarrays for predetermined directions was benchmarked against a conventional 3-element monopole array. These results are shown in Table II. Furthermore the radiation pattern obtained from one of the examples is illustrated in Fig. 6.

TABLE II
GAIN OF CONVENTIONAL 3-ELEMENT ARRAY AND ARRY OF SUBARRAY

ϕ_0	Conventional Array (dB)	Array of Subarrays (dB)
30°	4.3	6.4
60°	4.1	6.36
90°	4.4	5.57
120°	4.3	6.36
150°	4.1	6.4
180°	4.0	6.84
210°	5	4.8
240°	3.3	7.05
270°	4.5	7
300°	4.2	7.05
330°	5	4.8
360°	4.8	6.84

Notable improvements in gain were obtained. In addition enhancement of front-to-back ratio and lower side lobes were also observed.

V. CONCLUSION

This paper describes an approach to achieving an array of subarrays. Individual system components were analyzed, designed and manufactured. Also the benefits of an array of subarrays have been illustrated through the increase of gain in predetermined directions. This concept offers an additional degree of pattern control and provides great potential to application that utilize beam forming (e.g. sensor arrays, direction finding and smart antenna technology).

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